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ORIGINAL ARTICLE

Productivity and economics of lowland rice as influenced by incorporation of N-fixing tree biomass in mid-altitude subtropical Meghalaya, North East India

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Abstracts The climatic conditions of North East India are favorable for trees to produce biomass in the form of foliage and twigs that are very rich in essential plant nutrients. Effective recycling of this biomass would help meet the nutritional requirement of crops. Field experiment was conducted in *kharif* (June–November) seasons for consecutive 3 years (2003, 2004, and 2005) at a lowland farm, subtropical Meghalaya (950 m asl), India, to study the effect of incorporating N-fixing tree biomass (leaves and twigs) on productivity and economics of rice (*Oryza sativa* L.). Fresh biomass from five tree species including erythrina (*Erythrina indica*), acacia (*Acacia auriculiformis*), alder (*Alnus nepalensis*), tree bean (*Parkia roxburghii*), and cassia (*Cassia siamea*) were applied at a rate of 10 t/ha. A plot with recommended NPK rate (80:60:40 kg/ha) and a control plot were also maintained for comparison. Among the tree species used, the biomass of *E. indica* was superior in terms of N (3.2%), P (0.47%), K (1.5%), and organic C (18.8%) contents. In the first and second year, productivity of rice was high with recommended NPK rate (4.82 t/ha in 2003 and 5.08 t/ha in 2004) followed by rice with incorporation of *E. indica* biomass. In the third year of the experiment, effects of tree biomass incorporation on growth, yield and yield attributes surpassed those of the recommended NPK rate, with the exception of *A. nepalensis* biomass. In that year, the maximum grain yield was recorded under *E. indica* treatments, exceeding yields under the recommended NPK rate and control by 10.5 and 69.3%, respectively. Incorporation of tree biomass significantly improved (14–19% N and 62–83% P over control) the stocks of soil available N and P. Treatment with *A. auriculiformis* and *E. indica* biomass resulted in significantly higher soil organic C content which exceeded that under the recommended NPK rate by 10.3 and 9.2% and that under the control by 15.2 and 14%, respectively higher by species. The highest net return was recorded with the recommended NPK rate ($ 381/ha) followed by *E. indica* ($ 303/ha). Since the local farmers are resource poor and rarely use chemical fertilizers, application of plant biomass, particularly that of *E. indica*, to lowland rice is a recommendable option to improve productivity and income, and to sustain soil health.

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Introduction

Agriculture is the basic livelihood of the people in North Eastern Region of India. Rice, the major staple food of the region, is typically cultivated without any fertilizer and manure. The resource poor farmers of the region, in general, and hill farmers, in particular, rarely use synthetic fertilizer. They use whatever small quantity of organic manure is available for vegetable production (Das et al. 2008). As a result, the average productivity of rice in the region is very low (1.6 t/ha). The region is still in deficit of about 1 million tons of rice (Munda et al. 2006). At the same time, the region has plenty of on-farm resources such as biomass of weeds, forest litter, leaves, and twigs from pruning and lopping of trees on bunds around the field and in agroforestry systems. This biomass is usually left unutilized or burnt. However, in most cases, this biomass is very rich in essential nutrients (Das et al. 2006). If the available biomass in and around the farm can be effectively recycled, it could be an alternate source of nutrient in place of organic manure. The importance of effective recycling of on- and off-farm resources (crop residues, tree, shrub, weed biomass etc.) in organic rice production in North East India has been stated by Tripathy et al. (2007).

The role of green manure as a source of organic matter and its solubilizing effect on soil nutrients was well-documented (Rasal et al. 1988; Zaharah and Bah 1997). Uyovbisere and Elemo (2002) studied the incorporation of tree leaves in crop production and observed higher yield and nutrient uptake of maize with neem (*Azadirachta indica*) leaves. Tree leaves, especially those from N-fixing species, could be the utilizable organic materials for recycling in crop production. Decomposition of these materials is very fast due to their narrow C:N ratio; 50% of nutrients are released within a month in species like *Parkia biglobosa* and *A. indica* (Uyovbisere and Elemo 2002). Chaphale and Badole (1999) reported significant improvement in soil physical as well as chemical properties (soil organic carbon, total and available N contents) due to addition of *Glyricidia spp*. foliage. Higher soil nutrient availability and grain yield of crops due to application of *Leucaena leucocephala* over farmyard manure (FYM) and vermicompost was also reported by other workers (Bellakki and Badanur 1993; Durgude and Patil 1997). In North India, leaf litter of poplar (*Populus deltoides*), eucalyptus (*Eucalyptus hybrid*) and dek (*Melia azedarach*) is used by the farmers in crop fields (Singh et al. 1989). *Lantana camara* residues have been used to increase the nutrient availability and crop yield (Kayuki and Wortmann 2001; Kolawole et al. 2004; Sharna et al. 2003; Saha et al. 2008). The nutrient supply through organic manure not only reduces the dependence on chemical fertilizers but also improves the soil structure, encourages the growth and activity of mycorrhizae, and other beneficial organisms in the soil, alleviates the deficiency of secondary, and micronutrients, besides sustaining higher productivity due to improved soil health (Tomar et al. 2001). The growing problem of availability of farmyard manure for crop production, especially under organic farming, could be mitigated through addition of biomass from the trees growing abundantly in the North Eastern Region of India, especially those which are leguminous in nature, namely, *Erythrina indica*, *Acacia auriculiformis*, *Alnus nepalensis*, *Parkia roxburghii*, *Cassia siamea* etc. The biomass production by tress and shrubs is high in the region mainly due to high rainfall and congenial humidity. Bujarbaruah (2004) reported that the region has a potential of about 47 million tons of organic manure including 9 million tons of crop residues.

The present study intended to assess the effects of incorporating the biomass of N-fixing tree species on crop productivity, soil fertility and income generation in the lowland rice under organic production system.

Materials and methods

Experimental site

The field experiment was conducted at a low land farm, Division of Agronomy, ICAR Research Complex for NEH Region, Umiam, Meghalaya under irrigation. The farm is located at 25°30′N latitude and 91°51′E longitude with an elevation of 950 m above mean sea level. The soil of the experimental field was low in available P (6.9 kg/ha), medium in N (277 kg/

ha), and high in K (258 kg/ha). The pH and organic C content of the soil were 5.1 and 2.6%, respectively. The experimental soil was a sandy clay loam in texture.

Weather parameters

In 2003, minimum and maximum temperature ranged between 12–21 and 23–28°C, respectively. A total of 1,995 mm of rainfall was received during the cropping season in that year. In 2004, minimum and maximum temperature ranged between 12–20 and 23–28°C, respectively, and a total rainfall of 2,277 mm was received. In 2005, minimum and maximum temperature ranged from 12 to 21 and from 24 to 29°C, respectively. The rainfall received during the cropping season in that year was 1,190 mm.

Field experiment

The field experiment was conducted in *kharif* seasons (rainy season from June to November) for three consecutive years (2003, 2004, and 2005). The seven treatments consisted of incorporation of fresh leaf and twig biomass, i.e., T1: *Erythrina indica* 10 t/ha, T2: Alder (*Alnus nepalensis*; actinorhizal tree species) 10 t/ha, T3: Tree bean (*Parkia roxburghii*) 10 t/ha, T4: Acacia (*Acacia auriculiformis*) 10 t/ha, T5: Cassia (*Cassia siamea*) 10 t/ha, along with T6: Recommended NPK rate (80: 60:40 kg/ha), and T7: Control (no fertilizer and manure) under a randomized block design experiment (RBD) with three replicates. The high yielding rice variety 'Sahsarang 1' was transplanted in the first week of July at a spacing of 20 × 15 cm.

Application of biomass and fertilizer

All the biomass (leaves and twigs) was applied 20 days ahead of transplanting to the main field and incorporated along with spading/trampling. For supplying N, P, and K, urea, single super phosphate (SSP), and muriate of potash (MOP) were used in the recommended NPK plots. A half dose of N and a full dose of P and K were applied as basal application. The remaining half dose of N was divided in two equal portions and applied at panicle initiation and flowering stage. Except for the application of fertilizer in NPK treatment, no other synthetic agrochemicals were used in the experimentation.

Pest and disease management

For pest and disease management, a uniform dose of neem cake was applied to the soil (150 kg/ha) during last ploughing. Two sprays of neem oil (2 ml/l) were given at panicle initiation and heading stage to prevent pest and disease problems. Two hand weedings were conducted at 25 and 45 days after transplanting (DAT).

Plant sampling

The growth (plant height, tillers/hill, and dry matter production) and yield parameters (panicles/m^2, effective grains/panicle, and test weight) were measured at maturity at randomly selected 5 hills in each plot from the second year onwards. In the first year (2003), only grain and straw yield data were observed. Root parameters and leaf area index (LAI) measurements were taken at 50% flowering stage from randomly selected 5 hills. The plants were carefully uprooted and roots were washed in tap water. Root volume was measured in a one litre measuring cylinder by the water displacement method. LAI was measured using a portable plant canopy analyzer (CI-110 digital plant canopy analyzer, CID Inc., USA). The post-harvest data on total biomass, grain yield, and test weight were recorded. Harvest Index (HI) was computed by dividing the grain yield (at 14% moisture content) by the total biomass production and multiplying it by 100.

Plant and soil analysis

At harvest, grain, and straw samples of rice were analyzed (one composite sample from each treatment in each replication) for total N using a micro-Kjeldahl method, while total P and K were determined using sulfuric–nitric–perchloric acids digest (Prasad 1998). Nutrient uptake (for above ground biomass only) was estimated by multiplying the N, P and K concentration (%) of grain and straw with their respective yield in kg/ha and summing up the two values. The post-harvest soil samples were collected (one composite sample from each treatment in each replication) from 0 to 20 cm horizon for analyzing the available macro- and micro-nutrient status. The soil samples were analyzed for alkaline permanganate oxidizable N, 0.5 M $NaHCO_3$ extractable P, and 1 N NH_4OAc

exchangeable K as per the procedure described by Prasad (1998). Organic carbon (OC) was analyzed by dichromate oxidation and titration with ferrous ammonium sulfate (Walkley and Black 1934). The total content of micronutrients in soil was determined with an atomic absorption spectrophotometer (Analytik Jena, Germany) following the digestion with nitric and perchloric acids. Tree biomass consisted of leaves and twigs (5 samples for each species) were analyzed for their NPK (Prasad 1998), Organic C (Walkley and Black 1934) and moisture content.

Economic evaluation

The cost of cultivation and return were calculated based on the prevailing market price of the input and produce. The cost of fertilizer input was $ 0.1/kg, $ 0.073/kg, and $ 0.093/kg for urea, single super phosphate (SSP), and muriate of potash (MOP), respectively. Labor charge was $ 1.40/man-days (8 h). For collection and incorporation of 10 tons of biomass about 50 man-days were required. The cost of rice and straw was $ 0.12/kg and $ 0.006/kg, respectively. Net Return/$ invested (NRP) was obtained by dividing the net income by the cost of cultivation.

Statistical analysis

The plant and soil data were statistically analyzed using the *F*-test (Gomez and Gomez 1984). Test of significance of the treatment differences was done on the basis of the *t*-test. The significant differences between treatment means were compared with the critical difference (CD) at a 5% level of probability. The difference between two treatment means, which were higher than the respective CD values, were considered as significant.

Results and discussion

Nutrient composition of tree biomass

There was a marked variation in the nutrient composition of biomass of different tree species used in the experiment (Table 1). The N content varied from 2.24% (*A. nepalensis*) to 3.24% (*E. indica*). *A. auriculiformis* biomass contained 3.19% of N. The highest P and K contents were also found in *E. indica* biomass. The same species also had highest moisture content (71%). High nutrient content especially that of N in the biomass of trees, such as *L. leucocephala* (3.25%), was also reported by Tomar et al. (2001).

Growth and yield attributes of rice

The incorporation of different tree biomass had a significant effect on growth and yield attributes of rice (Tables 2, 3, and 4). In the second year of experimentation (2004), all the growth (height, tillers/m^2, biomass, root length, and root volume) and yield attributes (panicles/m^2, grains/panicle, and test weight) were highest under the recommended NPK rate, followed by the incorporation of *E. indica* biomass. These values were at par with those of *P. roxburghii*, *A. auriculiformis*, and *C. siamea*. The highest growth and yield attributes in the third year (2005) were observed with incorporation of *E. indica* biomass that were, however, at par with all other species (except for root volume, LAI and dry matter production with *A. nepalensis* which were significantly lower than *E. indica*) and the recommended NPK rate. The performance of rice with recommended NPK rate in the third year was slightly worser than that under the incorporation of tree biomass, except alder biomass which was associated with the lowest values of growth and yield attributes

Table 1 Biomass nutrient composition (%) of different species used in the experiment (average of 2003 and 2004)

Tree biomass (leaves and twigs)	N	P	K	Moisture	Organic carbon
E. indica	3.2 ± 0.16	0.47 ± 0.06	1.54 ± 0.13	71 ± 1.79	18.8 ± 0.82
A. nepalensis	2.2 ± 0.10	0.41 ± 0.04	1.37 ± 0.07	66 ± 1.90	16.9 ± 0.79
P. roxburghii	2.5 ± 0.12	0.40 ± 0.05	1.52 ± 0.11	69 ± 2.50	16.9 ± 0.66
A. auriculiformis	3.0 ± 0.19	0.43 ± 0.05	1.36 ± 0.07	68 ± 1.67	14.1 ± 0.40
C. siamea	2.5 ± 0.11	0.39 ± 0.06	1.17 ± 0.06	66 ± 2.10	17.3 ± 0.84

NB: ± values denotes standard deviation from mean

Table 2 Effect of various treatments on growth attributes of lowland rice

Treatments	Dry matter production (g/hill)		Tillers/m^2		Plant height (cm)	
	2004	2005	2004	2005	2004	2005
E. indica[a]	72.5	86.5	246.0	285.3	86.6	91.2
A. nepalensis	64.8	63.8	242.3	246.6	81.6	86.4
P. roxburghii	68.6	75.6	223.0	268.0	85.0	86.9
A. auriculiformis	70.7	79.7	242.0	284.0	85.2	90.8
C. siamea	71.2	78.3	244.7	283.7	85.0	89.0
Rec. NPK[b]	74.1	74.5	256.3	256.0	87.8	87.3
Control	56.3	60.6	175.0	228.0	77.7	83.2
Sem ±[c]	3.07	5.2	12.2	15.19	1.64	2.00
CD[d] ($P = 0.05$)	9.30	15.8	37.0	46.0	5.03	6.14

[a] Application rates for biomass were 10 t/ha

[b] 80:60:40 kg NPK/ha

[c] Sem ± standard error of means

[d] CD critical difference (the differences between treatment means are significant if exceed the respective CD value)

Table 3 Effect of various treatments on root growth and leaf area index (LAI)

Treatments	Root length (cm)		Root volume (cm^3/hill)		LAI	
	2004	2005	2004	2005	2004	2005
E. indica[a]	18.9	21.5	43.6	72.3	1.95	2.02
A. nepalensis	18.3	19.1	37.8	40.6	1.62	1.77
P. roxburghii	18.5	20.7	39.5	52.4	1.86	1.90
A. auriculiformis	18.6	20.0	41.7	70.5	1.90	2.02
C. siamea	19.6	19.3	42.4	66.3	1.86	2.04
Rec. NPK[b]	19.7	19.9	45.8	47.8	1.78	1.80
Control	17.0	18.3	31.3	37.4	1.46	1.48
Sem ±	0.89	1.16	1.58	2.13	0.09	0.07
CD ($P = 0.05$)	2.73	3.56	4.85	6.47	0.28	0.22

[a] Application rates for biomass were 10 t/ha

[b] 80:60:40 kg NPK/ha

among all the biomass treatments. The control plot demonstrated significantly lower values of growth and yield attributes in all the 3 years of experimentation. The higher growth and yield attributes with incorporation of tree biomass might be ascribed to the cumulative effect on improvement in the nutrient status and physical properties of soil due to decomposition of biomass and better utilization of nutrients by the crop (Escalada and Ratilla 1998; Singh et al. 1998). The improvement in crop growth and yield attributes of wheat due to litter inputs from non-N-fixing trees, such as *Populus deltoides*, *Eucalyptus hybrid*, and *Melia azedarach* in Northern India and Gharwal region of Himalayas under integrated input management systems has been observed by other researchers (Singh et al. 1989, 1998; Bhatt et al. 1997).

Rice yields

Incorporation of tree biomass had a significant effect on grain, straw yield, and total biomass production of rice (Table 5). In the first year (2003), the highest grain yield (4.82 t/ha) was recorded with

Table 4 Effect of various treatments on yield attributes of lowland rice

Treatments	Effective panicles/m^2		Panicles/hill		Effective grains/panicle		Test weight (g)	
	2004	2005	2004	2005	2004	2005	2004	2005
E. indica[a]	211.3	251.3	8.33	9.53	162.7	185.2	23.67	24.66
A. nepalensis	183.0	231.7	7.46	7.54	153.4	165.6	23.30	23.44
P. roxburghii	198.0	244.7	7.73	8.33	156.5	174.8	23.41	24.45
A. auriculiformis	206.7	252.0	8.27	8.93	160.3	174.4	23.70	24.28
C. siamea	203.7	248.7	8.10	8.17	157.7	173.1	23.58	24.59
Rec. NPK[b]	227.7	235.0	8.53	7.75	168.9	169.2	23.76	23.83
Control	161.0	201.3	6.2	6.40	146.3	151.5	22.69	23.31
Sem ±	17.1	16.12	0.55	0.46	7.81	7.98	0.36	0.36
CD ($P = 0.05$)	52.49	49.48	1.68	1.41	23.97	24.30	1.11	1.11

[a] Application rates for biomass were 10 t/ha

[b] 80:60:40 kg NPK/ha

recommended NPK rate followed by that with incorporation of *E. indica* (4.45 t/ha) and *P. roxburghii* biomass (4.13 t/ha). These yields were respectively 72, 60, and 47% higher than under the control yield. In the following year, i.e., 2004, the trend remained almost same and grain yields recorded with recommended NPK rate and *E. indica* were 62 and 54% higher than control, respectively. However, a significantly higher grain yield of rice in third year was recorded with incorporation of *E. indica* biomass (5.67 t/ha) that remained at par with recommended NPK rate and all other biomass except *A. nepalensis* (4.67 t/ha). The percentage yield increase with recommended NPK rate over control in the third year was 53%, whereas, in case of *E. indica* it was 69%. Similar trend was observed with respect to straw and total biomass yield. The results clearly showed the positive cumulative effects of biomass application over the consecutive years. Such positive effects of incorporation of biomass on crop productivity were previously reported for various tree species including *Leucaena leucocephala* (Durgude and Patil 1997), *Azadirachta spp*. (Murthy et al. 1990; Uyovbisere and Elemo 2002), *A. nepalensis*,

Table 5 Effect of various treatments on productivity and harvest index (HI) of rice

Treatments	Grain yield (t/ha)			Straw yield (t/ha)			Total biomass (t/ha)			HI		
	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005
E. indica[a]	4.48	4.83	5.67	6.55	7.12	7.77	11.03	11.95	13.44	40.68	40.46	42.14
A. nepalensis	3.50	4.10	4.67	5.66	6.11	6.45	9.16	10.21	11.12	38.18	39.91	42.09
P. roxburghii	4.13	4.40	5.24	6.20	6.85	7.16	10.34	11.25	12.40	39.90	39.92	42.27
A. auriculiformis	3.92	4.66	5.30	5.83	6.90	7.49	9.74	11.56	12.80	40.37	40.31	41.45
C. siamea	3.99	4.55	5.58	5.83	6.69	7.46	9.82	11.43	13.20	40.71	40.46	42.27
Rec. NPK[b]	4.82	5.08	5.13	6.88	7.34	7.05	11.69	12.42	12.18	41.28	40.93	42.06
Control	2.80	3.13	3.35	4.18	4.75	5.04	6.98	7.88	8.30	40.39	39.72	40.30
Sem ±	0.19	0.15	0.25	0.39	0.33	0.36	0.56	0.45	0.64	0.97	0.86	0.78
CD ($P = 0.05$)	0.58	0.46	0.77	1.19	1.02	1.19	1.71	1.65	1.96	NS	NS	NS

NS not significant

[a] Application rates for biomass were 10 t/ha

[b] 80:60:40 kg NPK/ha

L. camara (Gopinath et al. 2008; Saha et al. 2008) and *Eupatorium adhenophorum* (Das et al. 2006). The result indicated that manuring with N-fixing tree leaves imposed marked residual effect and improved productivity due to cumulative effect in each subsequent year. The higher grain and straw yield with incorporation of biomass might be ascribed to improvement in the nutrient status and physical properties of soil with the decomposition of leaves and better use of nutrients by the crop (Badanur et al. 1990; Escalada and Ratilla 1998). The harvest index (HI) remained unaffected by different treatments. This was due to the fact that the biomass production also increased along with grain yields proportionately, resulting in a lower influence on HI (Munda et al. 2006).

Nutrient concentration and uptake

The different treatments had a negligible influence on the nutrient concentration in grain and straw of rice (Tables 6, 7). The uptake was significantly influenced by the incorporation of biomass and recommended NPK rate. The nutrient uptake by rice followed the similar trend to that of grain yield and biomass production. Therefore, the highest nutrient

Table 6 Nutrient concentration (%) of rice grain and straw under various treatments

Treatments	Grain						Straw					
	N		P		K		N		P		K	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
E. indica[a]	1.33	1.39	0.29	0.31	1.29	1.36	0.65	0.70	0.20	0.22	1.41	1.48
A. nepalensis	1.20	1.26	0.27	0.26	1.17	1.27	0.59	0.60	0.16	0.17	1.37	1.41
P. roxburghii	1.20	1.30	0.28	0.29	1.21	1.22	0.63	0.63	0.19	0.20	1.38	1.45
A. auriculiformis	1.30	1.32	0.27	0.30	1.22	1.25	0.64	0.68	0.20	0.20	1.38	1.42
C. siamea	1.30	1.31	0.27	0.29	1.20	1.23	0.63	0.63	0.09	0.19	1.39	1.42
Rec. NPK[b]	1.20	1.30	0.26	0.26	1.22	1.23	0.60	0.63	0.18	0.18	1.36	1.41
Control	1.20	1.22	0.23	0.23	1.17	1.18	0.54	0.57	0.18	0.17	1.28	1.35

[a] Application rates for biomass were 10 t/ha

[b] 80:60:40 kg NPK/ha

Table 7 Nutrient uptake (kg/ha) under various treatments and significance of treatment effects

Treatments	Grain						Straw					
	N		P		K		N		P		K	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
E. indica[a]	64.24	78.8	14.0	17.6	62.3	77.7	46.3	54.4	14.24	17.1	100.4	115.0
A. nepalensis	42.0	58.8	11.07	12.14	48.0	59.3	36.0	38.7	9.78	10.9	83.7	90.3
P. roxburghii	49.6	68.1	12.32	15.2	53.2	63.9	43.2	45.1	13.0	14.3	94.5	103.8
A. auriculiformis	60.56	69.9	12.58	15.9	56.8	66.3	44.2	50.9	13.8	14.9	95.2	106.4
C. siamea	59.2	73.1	12.29	16.18	54.6	68.6	42.1	47.0	12.7	14.2	93.0	106.0
Rec. NPK[b]	60.9	66.7	13.21	13.34	62.0	63.1	44.0	44.4	13.2	12.7	99.8	99.0
Control	37.6	40.9	7.20	7.71	36.6	39.5	25.6	28.7	8.55	8.56	60.8	68.0
Sem ±	1.25	1.41	0.54	0.56	1.68	2.03	1.39	1.42	0.42	0.43	2.10	2.25
CD ($P = 0.05$)	3.81	4.30	1.63	1.72	5.12	6.20	4.25	4.33	1.29	1.32	6.37	6.85

[a] Application rates for biomass were 10 t/ha

[b] 80:60:40 kg NPK/ha

uptake in the third year was observed with incorporation of *E. indica* biomass followed by that with *A. auriculiformis* and *C. siamea* biomass. The lowest uptake was found under the control. *E. indica* incorporation increased NPK uptake by 93, 128, and 97% compared to control and 18, 32, and 23% over recommended NPK rate, respectively. Higher nutrient uptake due to application of green leaf manure from *Glyricidia spp, L. leucocephala*, and *Albizia lebbek* were also reported in rainfed sorghum (Bellakki and Badanur 1993), pearl millet (Durgude and Patil 1997), and irrigated basmati rice (Bhoite 2005).

Post-harvest soil fertility

After the harvest, soil samples were analyzed for macro- and micro-nutrients (Tables 8, 9). Biomass from all the species showed positive effect on the available soil nutrient status, particularly on the available N and P stocks. The available K status was not influenced by the different treatments. While the highest available N stocks were recorded with *E. indica* biomass, the highest P stocks were recorded with *C. siamea*. Organic C content was also improved significantly due to tree biomass incorporation. Incorporation of *A. auriculiformis* and *E. indica* resulted in maximum improvement of organic C content which was 10.3 and 9.2% higher than that under recommended NPK rate and 15.2 and 14% higher than that in control, respectively. The positive effects of tree biomass incorporation on the micronutrient status of the soil were not significantly different among the species. Available Fe stock was the highest with recommended NPK rate, followed by *A. nepalensis*. The highest Mn and Cu stock was associated with *A. auriculiformis* and *P. roxburghii*, respectively. A higher nutrient availability due to application of biomass (green leaf manure) from *Glyricidia spp*., *L. leucocephala*, *A. lebbek*, *A. indica*, *Cajanus cajan*, *Crotolaria tetragona*, *Indigofera tinctoria* (Bellakki and Badanur 1993; Durgude and Patil 1997; Chaphale and Badole 1999; Murthy et al. 1990; Laxminarayana et al. 2006), and green manure (in situ growing and incorporation; Bhoite 2005) were reported. In another study, Murthy et al. (1990) found that the incorporation of *A. lebbeck* (4.7% N), *A. indica* (2.6% N), and *L. leucocephala* (3.2% N) leaves improved the available and total N status of soil. The mineralization of nutrients especially N, from green manure biomass, might have been rapid and was available throughout the crop growth period. In wet seeded rice, green manure incorporation made adequate N available at the critical stages of 58–80 days after sowing (DAS), enabling better nutrient uptake and higher yield. (Joseph et al. 2002). During the process of organic matter decomposition, organic acids are released that promote the solubilization of soil nutrients (such as phosphorus) making it more available to plants (Rasal et al. 1988; Table 10).

Table 8 Post-harvest NPK and organic C stocks under various treatments in the rice production system

Treatments	Organic C (%)		Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)	
	2004	2005	2004	2005	2004	2005	2004	2005
E. indica[a]	2.68	2.85	320.1	323.3	12.2	13.1	293	294
A. nepalensis	2.65	2.76	295.3	309.7	9.4	11.7	296	295
P. roxburghii	2.60	2.71	288.7	314.1	10.7	12.8	271	282
A. auriculiformis	2.75	2.88	299.3	307.5	11.2	12.3	275	278
C. siamea	2.63	2.82	317.8	322.5	12.4	13.2	280	298
Rec. NPK[b]	2.59	2.61	281.0	297.0	8.6	10.3	274	277
Control	2.51	2.50	269.4	270.7	7.4	7.2	254	265
Sem ±	0.04	0.05	13.54	18.27	0.85	1.31	11.7	10.4
CD ($P = 0.05$)	0.13	0.15	41.73	56.31	2.62	4.03	35.94	NS
Initial status	2.56	–	277	–	6.95	–	257.8	–

[a] Application rates for biomass were 10 t/ha

[b] 80:60:40 kg NPK/ha

Table 9 Soil micronutrient status (ppm) as influenced by various treatments

Treatments	Fe[c]		Mn[d]		Zn[e]		Cu[f]	
	2004	2005	2004	2005	2004	2005	2004	2005
E. indica[a]	1.48	1.51	0.50	0.55	0.05	0.04	0.17	0.18
A. nepalensis	1.65	1.85	0.53	0.58	0.04	0.05	0.15	0.15
P. roxburghii	1.25	1.32	0.65	0.65	0.04	0.04	0.21	0.21
A. auriculiformis	1.22	1.23	0.70	0.73	0.04	0.05	0.18	0.20
C. siamea	1.38	1.41	0.64	0.63	0.04	0.04	0.15	0.16
Rec. NPK[b]	1.85	1.59	0.61	0.61	0.04	0.04	0.15	0.13
Control	0.92	0.97	0.39	0.40	0.03	0.04	0.10	0.09
Sem ±	0.12	0.14	0.04	0.04	0.005	0.005	0.023	0.023
CD ($P = 0.05$)	0.38	0.43	0.12	0.12	0.016	0.15	0.08	0.07
Initial status	1.11	–	0.38	–	0.04	–	0.14	–

[a] Application rates for biomass were 10 t/ha

[b] 80:60:40 kg NPK/ha

[c] Iron

[d] Manganese

[e] Zinc

[f] Copper

Table 10 Economics of treatments (based on three year means)

Treatments	Pooled grain yield (t/ha)	Pooled straw yield (t/ha)	Cost of cultivation ($/ha)	Gross return ($/ha)	Net return ($/ha)	NRP[c]
E. indica[a]	4.99	7.15	338.8	641.7	302.9	1.89
A. nepalensis	4.09	6.07	327.0	516.4	189.4	1.58
P. roxburghii	4.56	6.74	331.2	587.6	258.4	1.77
A. auriculiformis	4.63	6.74	335.6	596.0	260.4	1.78
C. siamea	4.71	6.66	337.6	605.2	267.6	1.79
Rec. NPK[b]	5.01	7.09	262.2	643.7	381.5	2.45
Control	3.09	4.66	207.2	798.7	191.5	1.92

[a] Application rates for biomass were 10 t/ha

[b] NPK in 80:60:40 kg/ha, cost of rice $ 0.12/kg, straw $.0.006/kg, wage of labor $ 1.4/man-days (8 h)

[c] Net return/$ invested

Economics

Unlike grain yield, the net return was the highest with recommended NPK rate ($ 381.5/ha) followed by that with incorporation of *E. indica* biomass ($ 302.9/ha). The net return per $ invested (NRP) followed this trend (Table 10). The lower net return with incorporation of biomass was mainly due to a higher labor cost required for collection and incorporation of biomass. However, if family labor is involved and thus ignored from economics, the incorporation of biomass would be beneficial. For example, a collection and incorporation of 10 tons tree biomass needs about 50 man-days, which would be $ 70. Deducting this amount from the cost of cultivation under *E. indica* would result in $ 269. That would give a net return of $ 372.9, which would be very close to net return from recommended NPK rate. It may be mentioned here that the opportunity cost of family laborers are negligible (maximum of $ 0.5/day) in the region due to a lack of sufficient employment opportunities. Moreover, using green manuring is an eco-friendly means of rice production, which would have a higher demand and is expected to fetch a 10–25% higher price than inorganic rice. Further, if the improvement in soil physico-chemical and biological properties would be considered, the incorporation of tree biomass would be much more beneficial compared to the inorganic means.

In conclusion, the application of tree biomass (leaves and twigs), especially from N-fixing species, such as *E. indica* not only improved the rice productivity and farm income but also maintained the soil health. This finding is important for regions like North Eastern part of India where farmers are resource poor and rarely use chemical fertilizer in crop production. Therefore, the available plentiful biomass particularly from trees and shrubs could be effectively recycled for organic rice production in the North East India.

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